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Current and Proposed Technologies for Bark Beetle Management

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Behavioral chemicals that disrupt mating and host tree selection are reducing losses to bark beetles. In the Pacific Northwest, thinning and selection of appropriate species have been the preferred management options, but pheromones—both attractants and antiaggregants—show promise. In the South, where single-species stands are especially vulnerable, inhibitory compounds and visual disruption may deter bark beetles from selecting valuable trees as hosts. In the Southwest, managers are combining slash management and thinning with semiochemicals and biological controls.

By Richard A. Goyer, Michael R. Wagner, and Timothy D. Schowalter

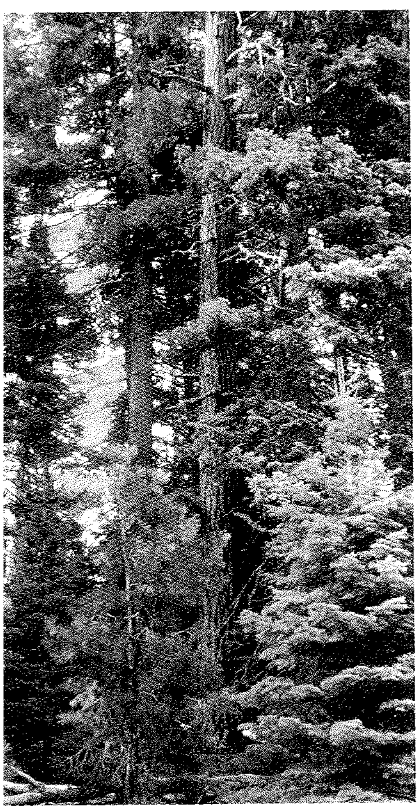
More than 40 percent of all described insect species are beetles, and there are some 30,000 species in the United States and Canada alone. Although only a handful of these species are known to cause direct tree mortality to our coniferous timber resources, the few that do often dominate the mature forest landscape, causing annual losses of millions of dollars as well as posing challenges for forest managers (Schowalter and Filip 1993). It has been said, in one form or another, that we harvest our trees when the beetles tell us it is time.

What options do we have, outside of pesticide applications and salvage operations? An overview of current regional management practices and new technologies shows that there are some alternative strategies for dealing with bark beetles.

The Pacific Northwest

Bark beetles of greatest concern in the Pacific Northwest include mountain pine beetle, *Dendroctonus ponderosae,* which attacks all pines in the region; western pine beetle, *D. brevicomis,* which attacks primarily ponderosa pine; Douglas-fir beetle, *D. pseudotsugae,* which attacks Douglas-fir (and rarely western larch); and the fir engraver, *Scolytus ventralis,* which attacks true firs. These insect species often occur together in stands of mixed conifers but segregate on the basis of tree species (Ross and Niwa 1997) and distinctive pheromones—the chemical attractants and repellents produced by host trees and insects.

Bark beetles, along with western spruce budworm and several root diseases, have often been blamed for the increasing forest health problems east of the Cascades. Although these insects kill host trees over large areas, their spread reflects the change in eastside conditions following a century of fire exclusion. Just as the recent catastrophic fires in eastside forests reflect a century of fuel accumulation in stands that historically experienced frequent low-intensity fires, the prevalence of bark beetle outbreaks reflects the increased den-



Photos by Timothy D. Schowalter

Forest health problems in eastern Oregon and Washington result from increased tree densities on arid sites, reflecting a century of fire exclusion. *Far left:* Dense, multistoried Douglas-fir and fir understories increase competition for resources and increase risk of fire and pest outbreaks. Removal of these mesic species is necessary to restore sustainable densities of site-adapted species (pine and larch) and forest conditions.

sity of water-stressed trees (Wickman 1992).

The historical role of bark beetles was to kill scattered injured or diseased trees and initiate decomposition and release of limiting nutrients. Now it is not uncommon for beetles to kill all trees in a dense stand whose understory trees increasingly compete for water and nutrients with overstory survivors of past fires. Bark beetle spread over this landscape has been assisted by the homogenization of stand structures and landscapes as stands are filled by dense thickets of young pines and by the spread of Douglas-fir and true firs across arid zones formerly dominated by sparse stands of pine and larch.

West of the Cascades, the Douglas-fir beetle is the major bark beetle. Small populations are generally restricted to diseased and wind-thrown trees. Following severe winter storms, populations reproducing in the fallen timber may grow sufficiently to kill live trees. Although the number of trees killed is relatively small, the beetles' potential threat has been sufficient to warrant a cultural recommendation that all log decks and as much salvage timber as possible be removed from the forest before beetle dispersal in May and to employ bark beetle management, particularly salvage removal, in areas of extensive windthrow.

A number of timber management options have been explored to reduce tree mortality caused by bark beetles. Thinning and selection of appropriate tree species address the conditions that lead to outbreaks and are the preferred means of prevention.

Thinning directly reduces the host resource base that supports beetle populations, reduces competition among trees for water and nutrients, reduces the effectiveness of pheromone communication between host-seeking beetles and beetles at suitable trees, and raises stand temperatures to levels that can reduce beetle survival (Amman et al. 1988). Studies of mountain pine beetle responses to host tree density indicate that tree mortality declines as density is decreased and virtually stops at average spacings of 20 feet (Sartwell and Stevens 1975).

Tree species selection also can influence bark beetle populations. Tree species planted off-site often become susceptible to bark beetles (Filip 1994), as do Douglas-fir and true firs when these natives of moist, high-elevation, and riparian forests are planted in more arid landscapes dominated by ponderosa pine and larch. Dense understories of firs persisted for decades in pine forests where growth was not sustainable under more arid conditions, increasing susceptibility to a variety of insects and pathogens, including Douglas-fir beetle and fir engraver.

Promoting a diversity of site-adapted tree species also reduces likelihood of beetle outbreaks. A mixed stand creates a more complex environment within which beetles must detect and reach suitable hosts. Some trees produce beetle-repelling pheromones that may protect neighboring trees. For example, verbenone has been found in the bark of living Pacific silver fir and western redcedar, which typically occur with Douglas-fir, suggesting that including these trees in Douglas-fir stands could create a nonattractive aerosol for Douglas-fir beetles (Schowalter et al. 1992).

Sanitation harvests to remove unhealthy and stressed trees have been used to reduce the potential for bark beetle outbreaks in fire- or wind-killed timber. Managers concerned about bark beetle outbreaks after a fire may want to remove desirable timber, but this may be problematic in inaccessible areas with complex terrain, especially with increasing restrictions on harvest activities. In any case, the window of opportunity for bark beetles to colonize trees is narrow. Trees killed by fire may not have sufficient bark to support the insects, and dead or injured trees that do have enough bark are suitable for beetle colonization for only a single year, after which the phloem is too dry for successful reproduction. Hence, significant outbreaks in response to fire disturbance are unlikely unless bark beetle populations are already large. But because wood volumes in eastside pine forests, after a century of fire exclusion, far exceed their historical levels, it may nevertheless be desirable to remove the excess wood—the invasive understory firs—and restore ecological processes underlying forest health, provided that the harvest methods do not jeopardize soil or stream integrity.

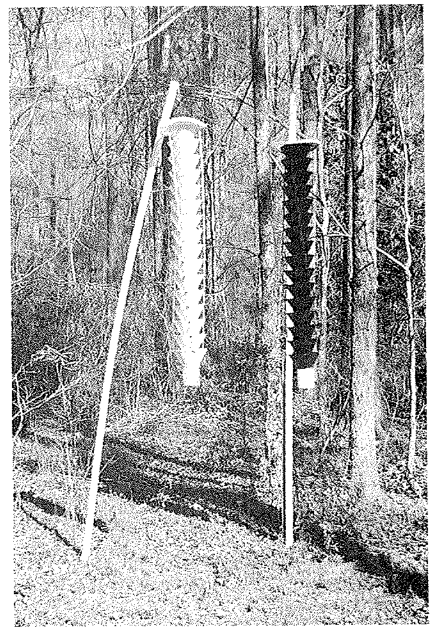
Two general approaches to bark beetle control with pheromones are undergoing registration testing at the Environmental Protection Agency (EPA). Ross and Daterman (1997) reported use of attractive baits (ethanol, methylcyclohex-2-en-1-ol, frontalin, and sudenol) distributed throughout large plots (259 hectares) during an outbreak of Douglas-fir beetles in northeastern Oregon. Large numbers of these beetles were lured to traps containing a mix of frontalin and sudenol and destroyed. Unfortunately, large numbers of the checkered beetle, *Thanasimus undatulus,* the primary predator of the Douglas-fir beetle, were also attracted and destroyed. Ross and Daterman (1997) suggested leaving sudenol out of the mix during the first two to three weeks of trapping to avoid capturing the checkered beetle. In any event, the data indicate that forest managers can influence the distribution of tree mortality attributable to bark beetles by placing attractive traps in nonhost areas or in areas where potential spillover of beetles can be easily monitored and controlled.

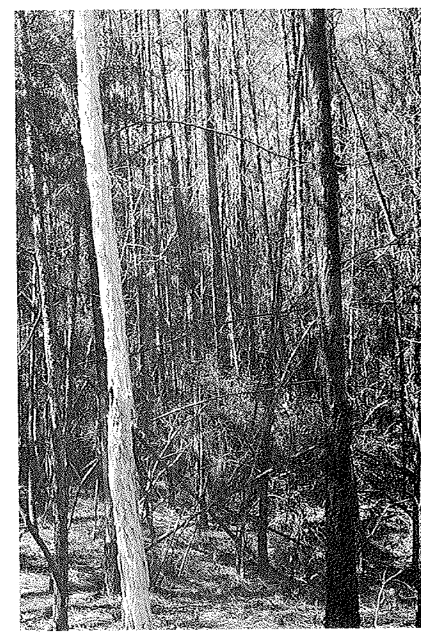
The second approach to bark beetle management with pheromones is the use of antiaggregant pheromones to repel beetles from susceptible stands. The most widely used repellent pheromone is 3-methylcyclohex-2-en-1-one (MCH). McGregor et al. (1984) reported the use of MCH to prevent Douglas-fir beetles from infesting wind-thrown trees. Ross et al. (1996) applied MCH at rates of 50, 100, and 150 bubble capsules per hectare (20, 40, and 60 grams per hectare, respectively) in 1-hectare plots of primarily mature Douglas-fir near beetle-infested trees during two years. Numbers of beetles trapped in attractant (frontalin plus sudenol) traps at the plot centers were significantly lower in all three MCH treatments compared with controls. No significant reduction in numbers of bark beetle predators was observed in MCH-treated plots, indicating that the remaining beetles in treated stands would be subjected to relatively higher rates of predation. These results demonstrate that MCH application can reduce the probability that susceptible stands of Douglas-fir will become infested with Douglas-fir beetles. Additionally, use of pheromones to induce bark beetle attack of designated trees has the potential to create snags for wildlife habitat (Ross and Niwa 1997), although fine-tuning this procedure to prevent unwanted attacks on surrounding trees would be necessary.

The South

In the South, intensive forest management practices favor single-species, relatively even-aged stands that provide extensive host material for bark beetles. Frequent fires set by lightning strikes, coupled with rapid tree growth, often lead to stand crowding and stress, increasing the trees' susceptibility to the southern pine beetle, *Dendroctonus frontalis;* the black turpentine beetle, *D. terebrans;* and three species of ips engravers—*Ips avulsus, I. grandicollis,* and *I. calligraphus* (Schowalter and Turchin 1993). The most damaging, however, is the southern pine beetle, which produces multiple broods per year and thus has great reproductive potential. If tree vigor is not maintained through periodic thinnings or by control tactics, infestations can expand rapidly through plantations of suitable hosts (loblolly and shortleaf pines) and kill hundreds of acres of trees. And in fact, areawide epidemics resulted in catastrophic losses in the mid-1980s and again in the early 1990s.

Until recently, control tactics (described in Thatcher et al. 1980) included salvage removal, cut-and-leave during summer months, and pesticides, such as lindane or chlorpyrifos. These are tied closely to such preventive measures as stand hazard ratings and frequent aerial detection and ground truthing activities (Thatcher et al. 1980). Routinely, forest pest specialists have recommended stand thinning to achieve long-term success in suppressing the southern pine beetle. Intermediate cuttings decrease basal area, reduce competition, and subsequently increase tree vigor and resistance to beetle attack (e.g., Brown et al. 1987).





Photos by G.J. Lenhard, Louisiana State University

Lindgren funnel traps, painted white or black, are being evaluated as visual disruptants that prevent bark beetles from finding host trees; researchers are seeking ways to achieve the same effects without having to paint the tree trunks.

Everyday forestry routines have changed, however. Resource managers are pursuing objectives other than timber production, including ecosystem- and landscape-level multiple-use management and endangered species protection. In these scenarios, trees have intrinsic as well as economic value and justify more individual expense and effort. To protect high-value areas, antiaggregant pheromones, such as verbenone (awaiting EPA registration), are becoming viable alternatives.

Verbenone is produced by male southern pine beetles. It has been found useful in controlling spot infestations both with and without felling of infested trees (Billings et al. 1997). Small spots (up to 80 trees) may be controlled with verbenone bags attached to newly attacked pines and adjacent uninfested trees. Two or more bags (applied at 40 milliliters per square foot of basal area) are nailed 10 to 12 feet above ground by workers using long-handled hammers. The bags release inhibitory verbenone for at least six weeks. Field studies revealed that infestation growth was reduced approximately 75 percent and control accomplished in 85 percent of treated stands. When verbenone was applied in larger infestations (up to 120 active trees) at 25 milliliters per square foot of basal area and infested trees were felled, infestation growth was reduced 82 to 99 percent and control exerted in 80 to 100 percent; the results were achieved in five southern states.

Another inhibitory compound, 4-allylanisole, or 4-AA, produced in the resin of various trees, has been shown effective in protecting individual trees in residential areas, woodpecker colonies, and parks. Developed primarily by USDA Forest Service and Mississippi State University scientists (Hayes et al. 1994), 4-AA is applied in vials or bags to repel southern pine beetles in search of hosts. Registration testing is under way, and if approved, 4-AA will provide a biorational alternative to chemical pesticide treatment (or harvesting) of high-value trees. Other host plant odors, including green leaf volatiles, are being investigated both singly and in concert with insect-produced pheromones to determine their roles in bark beetle management.

One new effort conducted collaboratively by the Forest Service and Louisiana State University Agricultural Center scientists (Strom et al., in press) has demonstrated that treatments to alter the appearance of trees hold great promise for disrupting the host selection process of aggressive bark beetle species like southern pine beetles, which attack almost exclusively dark, vertical silhouettes. The number of southern pine beetles and the predatory clerid beetle, *Thanasimus dubius,* caught in Lindgren funnel traps depends more on the color of the trap than on the semiochemical attractant inside. Compared with black traps baited with frontalure, an attractant, white traps without a semiochemical disruptant caught about 70 percent fewer southern pine beetles and 85 percent fewer *T. dubius.* In black traps with 4-AA repellent but no visual disruptant, a 50 percent reduction was observed. The combination of semiochemical and visual disruptants—4-AA repellent and white paint—in this study reduced trap catch by about 90 percent, the greatest reduction of any treatment combination. If ways other than painting trees white can be found to visually disorient bark beetles, such disruptive techniques could become operational.

Another direction for regulating populations of southern pine beetles involves enhancing the ability of parasites to respond effectively to increased beetle density. A series of short-term studies conducted in 1995–96 at the University of Arkansas substantiate the importance of nutrition for southern pine beetle parasitoids. An artificial diet, marketed as Eliminade™, is designed to increase longevity and fecundity of adult parasitoids. Analyses of data from summer 1996 indicate an increase in parasitoid density and percent of parasitism in field infestations treated with Eliminade.

The Southwest

Bark beetles and catastrophic fire risks are major forest health issues in the Southwest. In this region, weather conditions, fire suppression, grazing, and extensive harvesting of mature forests at the turn of the last century have created a vast forest of young, overstocked stands of conifers (Covington et al. 1997). These stands are currently reaching conditions that make them susceptible to bark beetles. Historical records indicate that the western pine beetle, which prefers mature trees, was the major pest, but because most of the mature forests have been replaced by high-density young forests, the troublesome bark beetles today are pine engravers—*Ips* sp.

Outbreaks of *Ips* pine engravers are initiated by stand management activities, such as thinning, and environmental stress factors, such as drought. Pine engravers tend to be associated with highly stressed trees or freshly cut slash, a characteristic that leads to pest management with an emphasis on sanitation and slash management approaches.

Management of *Ips* engraver populations in the 1990s employs an integration of slash management, stand thinning, semiochemicals, and potential biological control. Slash management treatments include the following:

- Felled trees and slash—pine engraver breeding grounds—should be removed quickly. Removal of all material larger than 4 inches in diameter has been a long-standing recommendation for engraver beetle control (Massey and Parker 1981).
- Reducing the length of residual bolts may be as effective as reducing diameter (Wesley 1995).
- Slash should dry as quickly as possible. Exposing slash to direct sunlight reduces attack by engraver beetles (Villa-Castillo and Wagner 1996), as does scattering slash to promote rapid drying (Livingston 1979).
- Forest operations should be timed to avoid generating fresh slash when beetles are emerging. Specific timing of forest operations depends on location, but generally by late summer to early fall engraver beetle adults have finished breeding. Slash produced in the fall will usually be unsuitable for beetles emerging the following spring (Livingston 1979).

For managing pine engraver beetles, like other bark beetles, thinning is a tool (Schowalter and Filip 1993). Thinning affects the microclimate of the stand, changing beetle behavior and reducing beetle attack in several ways. Thinning also increases tree resistance by increasing soil water availability, which affects resin flow (constitutive resistance), and by increasing carbohydrates, which increases the tree wound response (induced resistance) (Christiansen et al. 1987). Reducing stand density to site carrying capacity has always been good forestry and is also good pest management for bark beetles, including pine engravers.

Biological control of pine engraver beetles, a research topic in the 1990s, has drawn considerable interest from foresters and entomologists alike. A comprehensive assessment, however, suggests that operational control of *Ips* sp. is restricted to classical biological control, that is, introducing natural enemies of engraver beetles that have colonized into new areas (Kulhavy and Miller 1989). While biological control is not a current operational pest management tool, there is great potential for improving natural enemy regulation of pine engravers by modification of trapping methods and improving habitat for natural enemies similar to what Stephen (Department of Entomology, University of Arkansas) is attempting with the southern pine beetle.

The most widespread use of pheromones for *Ips* engraver management is detecting and monitoring beetle population intensity, extent, and periodicity (Shea 1994). Knowledge about periodicity of engraver beetles can be especially valuable in scheduling forest operations. As in the case for other bark beetles, the use of antiaggregation pheromones to control pine engravers shows promise and may soon be operational (Gibson 1994). It may be possible to trap-out—to eliminate—all engraver beetles in an isolated stand if the beetle population is small (Shea and Neustein 1995). This strategy, which has shown great promise in portions of Scandinavia and Europe, may be especially useful in managing introduced beetles in the early stages of establishment.

Summary

Although bark beetles are destructive to timber management, from an ecological perspective their role is to open the canopy, thin dense stands of stressed trees, and initiate decomposition. This role likely enhances health of surviving trees by reducing competition for water and nutrients, in effect serving as "nature's loggers." However, the fuel accu-

R.F. Billings, Texas Forest Service

Uncontrolled infestations of the southern pine beetle killed more than 7,500 acres of young plantations and mature stands on Indian Mounds Wilderness, Sabine County, Texas, in 1993.

mulation resulting from large numbers of dead trees also increases the risk of high-intensity fire for surviving trees. Resolving problems with fire and bark beetles depends on thinning, removing dense understories that fuel both bark beetle populations and fire, promoting predators and parasites, and using pheromones. This will require that forests be modified at the landscape scale to restore natural barriers to spread of fire or bark beetles and, potentially, to replace nutrient sources for parasitoids.

With lower timber harvests on federal land, rising stumpage values, and increasing demand, salvage and other existing technologies for minimizing economic losses to bark beetles will have to suffice until areawide silvicultural modifications are operational. In the interim, behavioral chemicals, alone or in concert with other disruptant tactics, will assist forest managers in protecting certain valuable timber resources.

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